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Development of an Ergonomic Padding System for Goalkeeper Undershirts: An Integrated Approach to Impact Point Protection and User Comfort

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Abstract: Goalkeepers face a significant risk of impact during football activities due to dynamic actions such as diving, falling, and making physical contact with the ground. Protective padding is typically employed to lessen the impact absorbed by the body; however, the choice of padding materials still poses challenges concerning impact absorption, thermal comfort, flexibility, and weight. This study aims to explore the properties of padding materials for goalkeeper undershirts and pinpoint material attributes that can achieve the right balance between protection and comfort for the user. The research utilizes a descriptive qualitative methodology through literature reviews, product evaluations, and interviews with goalkeepers. The analysis concentrates on impact characteristics, material features, impact absorption, thermal comfort, flexibility, and the positioning of protective padding. The findings suggest that the combination of impact-absorbing foam and breathable spacer fabric can be considered as a material concept for goalkeeper undershirts. The findings are expected to provide a reference for the development of more ergonomic and comfortable protective equipment for goalkeepers.

Keywords: goalkeeper; padding; impact protection; sportswear; material; ergonomics

Abstrak*: Kiper menghadapi risiko benturan yang cukup signifikan selama aktivitas sepak bola karena melakukan gerakan dinamis seperti* diving*, jatuh, dan kontak fisik dengan permukaan lapangan.* Padding *pelindung umumnya digunakan untuk mengurangi dampak benturan yang diterima tubuh. Namun, pemilihan material* padding *masih menghadapi tantangan terkait kemampuan penyerapan benturan, kenyamanan termal, fleksibilitas, dan bobot. Penelitian ini bertujuan untuk mengeksplorasi karakteristik material* padding *untuk* undershirt *kiper serta mengidentifikasi atribut material yang dapat mencapai keseimbangan yang tepat antara perlindungan dan kenyamanan bagi pengguna. Penelitian ini menggunakan metodologi deskriptif kualitatif melalui studi literatur, evaluasi produk, dan wawancara dengan kiper. Analisis difokuskan pada karakteristik benturan, karakteristik material, penyerapan benturan, kenyamanan termal, fleksibilitas, dan penempatan* padding *pelindung. Hasil penelitian menunjukkan bahwa kombinasi* foam *penyerap benturan dan* spacer fabric *yang memiliki kemampuan bernapas dapat dipertimbangkan sebagai konsep material untuk* undershirt *kiper. Hasil penelitian ini diharapkan dapat menjadi referensi dalam pengembangan perlengkapan pelindung bagi kiper yang lebih ergonomis dan nyaman.*

Kata kunci*: kiper;* padding*; perlindungan terhadap benturan; pakaian olahraga; material; ergonomi.*

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Introduction

Football is widely recognized as a high-intensity sport that requires complex physical abilities and involves continuous interaction between players, opponents, and the playing environment. Throughout a match, football players are required to perform various dynamic movements, including acceleration, sprinting, jumping, rapid changes in direction, body balance control, and repeated physical contact with the playing surface. These activities generate considerable mechanical stress on the musculoskeletal system, particularly when players perform movements involving sudden changes in speed, body rotation, or direct contact with external surfaces. Among the different playing positions, the goalkeeper has distinctive biomechanical characteristics because the role requires frequent execution of explosive and defensive movements, such as diving, jumping, stretching, falling, and rapid positional adjustments to prevent goal attempts. Unlike outfield players who generally maintain an upright posture during most phases of play, goalkeepers often place their bodies in vulnerable positions involving direct contact with the ground. Consequently, specific anatomical regions of the goalkeeper's body are exposed to repeated impact forces, increasing the potential risk of discomfort, bruising, and impact-related injuries (Luxbacher, 2012; FIFA, 2024).

The repeated occurrence of high-impact movements during goalkeeper activities highlights the importance of developing protective equipment that can effectively reduce mechanical loads while maintaining functional performance. Diving and landing actions are among the most common situations in which goalkeepers experience direct impact because the body must absorb forces generated from rapid movement and sudden contact with the playing surface. During these actions, several body regions, including the shoulders, elbows, hips, and lateral torso areas, frequently become primary impact points. Therefore, protective equipment designed for goalkeepers must be capable of minimizing impact transmission without interfering with movement efficiency and technical performance. Previous studies have emphasized that sports protective equipment plays an important role in reducing injury risks by controlling the magnitude and distribution of impact forces transferred to the body. McIntosh and McCrory (2005) demonstrated that protective materials with appropriate energy attenuation characteristics can reduce peak impact forces and decrease the amount of mechanical energy transmitted to human tissues. Similarly, Schmitt et al. (2008) reported that padded goalkeeper equipment could provide additional protection by reducing impact loads during football-specific movements. These findings confirm that padding systems are an essential component in the development of protective sportswear.

Although padding materials provide important protective functions, the development of an effective padding system requires careful consideration because increasing protection performance may influence other aspects of garment functionality. A protective material with high density or excessive thickness may improve impact absorption capability; however, these characteristics can also increase garment weight, reduce flexibility, restrict body movement, and negatively influence thermal comfort. For athletes who perform repeated high-intensity movements, these limitations may affect performance and wearing experience. Harris and Spears (2010) found that protective padding could effectively reduce impact forces, but inappropriate material characteristics may reduce mobility and increase discomfort during prolonged use. Furthermore, Wardiningsh et al. (2015) emphasized that the effectiveness of impact protective materials depends on multiple factors, including energy absorption capacity, material structure, thickness, deformation behavior, and thermal management performance. Therefore, the selection of padding materials for goalkeeper undershirts requires a multidimensional approach that considers not only mechanical protection but also flexibility, lightweight characteristics, ventilation capability, and compatibility with goalkeeper movement patterns.

Thermal comfort is a particularly important consideration in the design of protective sportswear because athletes experience increased metabolic heat production during intensive physical activities. Protective materials with compact structures may limit air circulation and reduce moisture evaporation, resulting in heat accumulation inside the garment. This condition may decrease user comfort, especially when protective equipment is worn during extended training sessions or competitive matches. Havenith (2002) explained that clothing systems used during physical activity must support effective heat transfer and moisture regulation to maintain physiological balance. Therefore, protective clothing design requires an appropriate balance between material density for impact protection and structural openness for thermal regulation. Materials that provide excellent ventilation may improve comfort but may not always provide sufficient impact attenuation, whereas highly protective materials may compromise breathability and flexibility.

Recent developments in material engineering and textile technology have encouraged the exploration of multifunctional materials for sports protective applications. Several studies have demonstrated that combining different material structures can improve the overall performance of protective sportswear by integrating complementary functional characteristics. Foam-based materials, such as ethylene vinyl acetate (EVA) foam and polyurethane (PU) foam, are widely used because of their lightweight properties, flexibility, and ability to absorb impact energy through controlled deformation mechanisms. These characteristics make foam materials suitable for applications requiring energy dissipation and impact reduction. However, foam-based materials may have limitations related to air permeability and thermal comfort, particularly when applied in dense structures. In contrast, spacer fabrics provide advantages through their three-dimensional porous structure, which supports air circulation, moisture transfer, and wearer comfort (Dias, 2015; Song et al., 2015). Nevertheless, spacer fabrics generally have lower impact absorption capability compared with foam materials, indicating that their application as the primary protective component may be limited (Van den Eijnde & Peeters, 2018).

Considering the different characteristics of available materials, previous research has suggested that an integrated material approach may provide a more effective solution than relying on a single material type. Troynikov et al. (2013) highlighted that the performance of sports protective equipment is influenced by the interaction between material properties, structural design, and user-specific requirements. Therefore, protective equipment should be designed as a comprehensive system that considers impact mechanisms, anatomical characteristics, movement patterns, and physiological comfort. In the context of goalkeeper undershirts, the placement, shape, and thickness of padding components are equally important because protective materials must remain aligned with impact-prone body areas during dynamic movements.

Despite significant developments in sports protective materials, previous studies have primarily focused on evaluating individual material characteristics or specific protective equipment components. Limited attention has been given to the development of an integrated padding system specifically designed for goalkeeper undershirts that simultaneously considers impact protection, ergonomic placement, flexibility, and thermal comfort. Existing research has not fully addressed how material selection and padding configuration can be optimized according to goalkeeper-specific impact patterns and movement requirements. This limitation indicates a need for further investigation into protective garment designs that integrate biomechanical considerations with material engineering principles.

Therefore, this study aims to investigate the characteristics of padding materials and develop an ergonomic padding concept for goalkeeper undershirts based on impact protection requirements, material performance, and user comfort considerations. The study focuses on identifying suitable material combinations and determining an appropriate

protective configuration that can reduce impact forces while maintaining flexibility, ventilation, and mobility. The findings of this research are expected to contribute to the development of goalkeeper protective equipment by providing a design framework that integrates impact protection, ergonomic principles, and functional requirements for high-performance sports activities.

Method

This study employed a qualitative descriptive research approach to investigate the characteristics and potential applications of padding materials for goalkeeper undershirts. This methodological approach was selected because it allows an in-depth exploration of material properties, protective functions, and user requirements based on descriptive analysis rather than experimental measurement. The study aimed to develop a comprehensive understanding of the relationship between padding material characteristics and the functional demands of goalkeeper activities, particularly in terms of impact protection, thermal comfort, flexibility, weight, and suitability for dynamic movements during football performance.

This study employed a qualitative descriptive research approach to investigate the characteristics and potential applications of padding materials for goalkeeper undershirts. This methodological approach was selected because it allows an in-depth exploration of material properties, protective functions, and user requirements based on descriptive analysis rather than experimental measurement. The study aimed to develop a comprehensive understanding of the relationship between padding material characteristics and the functional demands of goalkeeper activities, particularly in terms of impact protection, thermal comfort, flexibility, weight, and suitability for dynamic movements during football performance.

Product observations were carried out by examining existing goalkeeper protective equipment available on the market. The observation focused on identifying the types of materials used, the structural characteristics of padding systems, material thickness, shape configuration, and the anatomical placement of protective components. These observations provided practical insights into current design approaches and helped identify potential advantages and limitations of existing goalkeeper protective products.

In addition, interviews were conducted with four individuals who had previous experience as football goalkeepers. The interviews aimed to obtain user-based information regarding the types of impacts commonly experienced during goalkeeper activities, perceived comfort when using protective equipment, heat accumulation during prolonged use, limitations related to movement flexibility, and the users' expectations regarding additional body protection. The collected interview data were organized and categorized based on similarities in user experiences, perceived problems, and protection requirements.

The collected data were analyzed using a qualitative descriptive analysis technique. The researchers systematically compared various padding materials by considering several performance-related aspects, including impact absorption capability, structural flexibility, ventilation properties, material weight, functional advantages, and potential limitations. The results of this comparative analysis were then synthesized to identify the most relevant material characteristics for developing an ergonomic padding concept for goalkeeper undershirts. This approach provided a basis for designing a protective system that balances impact reduction performance with user comfort, mobility, and the specific activity requirements of goalkeepers.

Result and Discussion

The findings of this study demonstrate that goalkeeper activities involve distinct impact characteristics compared with outfield players due to the unique movement patterns and physical demands associated with the goalkeeper position. Unlike players in other positions

who primarily perform running, passing, and directional changes, goalkeepers frequently engage in high-impact movements, including diving, jumping, falling, and rapid body displacement to prevent scoring attempts. These actions often result in direct contact between specific body regions and the playing surface, generating repeated mechanical loads and impact forces that may increase the risk of discomfort or injury.

Based on the results obtained from the literature review, product observations, and interviews with experienced goalkeepers, several anatomical regions were identified as requiring additional protective consideration. The shoulder, elbow, lateral torso or rib area, and hip regions were found to be the most critical impact zones because these areas frequently become the primary contact points during diving, landing, and falling movements. The shoulder and hip areas are particularly exposed when goalkeepers perform side dives, while the elbows often experience loading when the goalkeeper uses the upper limbs to support or stabilize the body during landing. In addition, the rib and side-body regions may receive impact pressure during rotational movements or when the body slides across the playing surface after contact.

These findings indicate that the design of goalkeeper protective equipment should not rely solely on the selection of impact-absorbing materials but should also consider the distribution and anatomical placement of protective components. Therefore, identifying goalkeeper-specific impact zones is an essential step in developing an ergonomic padding system that can provide targeted protection while maintaining flexibility, mobility, and comfort during dynamic football activities.

The interview results obtained from goalkeeper participants revealed that impact events were most frequently experienced during diving movements, particularly when the body made direct contact with the playing surface after attempting to reach or block the ball. Participants described that these high-intensity movements often generated considerable pressure on specific body regions, especially during side dives, sudden falls, and landing phases. One participant reported that the elbows, shoulders, and hips were among the body areas that most frequently received impact because these regions commonly became the initial contact points between the body and the ground. These findings indicate that the repetitive nature of goalkeeper movements creates specific impact patterns that require targeted protection rather than uniform coverage across the entire body.

In addition to impact protection, the interviews also identified comfort-related challenges associated with the prolonged use of protective equipment. One participant emphasized that heat accumulation became a significant concern, particularly when wearing protective gear during extended training sessions or competitive matches. Excessive heat retention may reduce wearing comfort and potentially affect movement performance during high-intensity activities. Furthermore, participants reported that padding systems that lacked sufficient conformity with body contours could shift from their intended positions during dynamic movements. This displacement may reduce the effectiveness of impact protection because the protective components are no longer aligned with the areas most exposed to impact.

These findings demonstrate that the effectiveness of a goalkeeper protective system is not determined solely by the impact absorption capability of the padding material. Instead, an optimal protective design requires a comprehensive consideration of several factors, including material characteristics, anatomical placement, structural flexibility, body conformity, ventilation performance, and user comfort. Therefore, the development of goalkeeper undershirts should integrate protective and ergonomic considerations to ensure that the padding system remains functional, stable, and comfortable during various goalkeeper-specific movements.

From a material engineering perspective, foam-based materials provide significant advantages for the development of protective sports equipment due to their ability to absorb impact energy, lightweight characteristics, and relatively simple integration into garment-based protection systems. Foam materials can undergo controlled deformation when exposed to external forces, allowing them to absorb, dissipate, and reduce the amount of energy transferred directly to the human body. These characteristics make foam one of the most commonly applied materials in protective equipment. However, despite these protective advantages, dense foam structures may present limitations, particularly regarding thermal management and air circulation. The compact structure of high-density foam can reduce ventilation pathways, resulting in increased heat accumulation and moisture retention during prolonged physical activities. This limitation is particularly relevant for goalkeepers because their performance requires repeated explosive movements, rapid body displacement, and extended periods of activity while wearing protective equipment.

The impact attenuation performance of padding systems is influenced not only by the type of material but also by the structural characteristics, thickness, density, and mechanical response of the padding. Materials with the ability to deform progressively under impact loading can absorb a portion of the applied energy and distribute the remaining forces over a wider area before reaching the body surface. This mechanism helps minimize localized pressure and reduces the potential risk of injury caused by direct impact. Conversely, padding materials that are excessively rigid may reduce flexibility and restrict natural body movements, while materials that are too thin may provide insufficient energy absorption capacity. Therefore, the selection of padding materials requires a balanced consideration between impact protection performance, flexibility, weight efficiency, and compatibility with the dynamic movement patterns of goalkeepers.

The comparative analysis of several padding materials revealed that each material possesses specific functional advantages and limitations. Ethylene Vinyl Acetate (EVA) foam demonstrates favorable characteristics due to its lightweight structure, durability, and effective impact absorption capability, making it a potential candidate for primary protective components in goalkeeper undershirts. Polyurethane (PU) foam provides greater flexibility and cushioning properties, which may improve wearing comfort; however, its long-term durability under repeated compression and impact exposure requires further consideration. Memory foam offers superior body conformity because of its adaptive deformation characteristics, allowing the material to adjust to individual body contours. Nevertheless, its relatively higher weight and slower recovery response may influence movement efficiency during dynamic activities. Gel-based padding provides effective pressure distribution and impact dispersion through its viscoelastic properties; however, its higher material weight and production cost may limit its application in lightweight sportswear. Meanwhile, spacer fabric has a unique open three-dimensional structure that supports better air circulation, moisture management, and flexibility, although its ability to function as a primary impact-absorbing material remains relatively limited compared with foam-based materials.

Considering the different characteristics of these materials, the application of a single material alone may not be sufficient to achieve the required balance between protection, comfort, and mobility in goalkeeper undershirts. A protective system that relies solely on high-impact absorption materials may improve safety performance but may negatively affect thermal comfort and movement flexibility. Conversely, materials designed primarily for ventilation and comfort may not provide adequate protection against repeated mechanical impacts. Therefore, a combination of materials with complementary functions represents a more appropriate design strategy. Impact-absorbing materials can be strategically applied to high-risk impact zones, while materials with open structures can be incorporated into

surrounding areas to improve ventilation, reduce heat accumulation, and maintain user comfort.

Based on these considerations, the proposed material concept for goalkeeper undershirts involves the integration of foam-based padding as the primary impact protection component and spacer fabric as a supporting layer for ventilation and thermal regulation. The placement and distribution of padding should be determined according to the anatomical areas that experience the highest impact exposure, including the shoulders, elbows, lateral torso or rib regions, and hips. This targeted placement approach allows protective performance to be optimized while minimizing unnecessary weight addition and maintaining freedom of movement during goalkeeper-specific activities.

The findings further indicate that the effectiveness of a goalkeeper protective system is determined not only by the impact absorption capability of the selected material but also by the interaction between material properties, padding geometry, thickness, positioning, and body conformity. A well-designed padding system must remain stable during dynamic movements, follow body contours effectively, and provide protection without reducing mobility or increasing physical discomfort. Therefore, the development of a goalkeeper undershirt requires a holistic ergonomic design approach that integrates material selection, anatomical padding placement, structural configuration, and biomechanical demands associated with goalkeeper performance. This integrated approach is essential for achieving an optimal balance between impact protection, flexibility, thermal comfort, and functional usability.

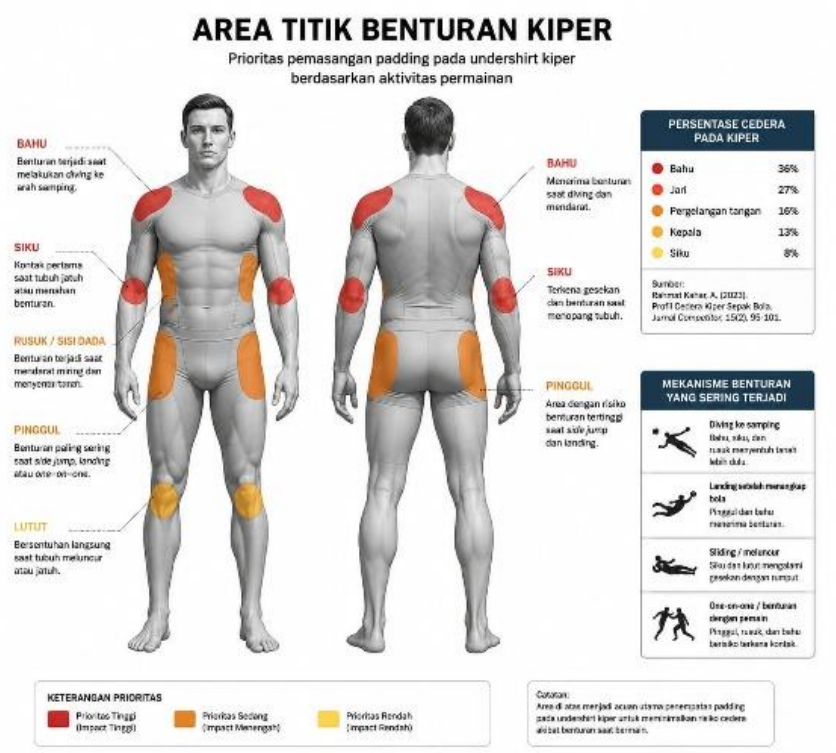

Figure 1. Impact Area

Figure 1 illustrates the priority areas for padding placement on goalkeeper undershirts based on the frequency and mechanism of impacts experienced during football activities. The figure shows that the shoulder, elbow, hip, and rib areas represent high-priority protection zones because these areas frequently experience direct contact with the playing

surface during diving, landing, and falling movements. The shoulder area is particularly vulnerable because it often becomes the first contact point when goalkeepers perform diving actions to reach the ball. Similarly, the elbow area requires protection because goalkeepers commonly use their arms to support body weight during falls and landing movements.

The hip and side-body regions also require additional protection because these areas frequently receive impact forces when the body rotates or slides after making contact with the ground. Meanwhile, the knee and other lower-impact areas are categorized as moderate- to low-priority zones, depending on the movement characteristics and frequency of contact. The distribution of these impact zones indicates that padding placement should not be uniform across the entire undershirt but should be adjusted according to the level of impact exposure and movement requirements.

The figure also highlights several common impact mechanisms experienced by goalkeepers, including diving, landing, sliding, and physical contact with other players. These movements generate different impact patterns and require a protective system capable of absorbing energy while maintaining flexibility and mobility. Therefore, the design of goalkeeper undershirts should integrate material selection, padding thickness, shape, and anatomical placement to ensure that protection is provided at critical impact points without reducing comfort and movement performance.

Conclusion

Based on the research conducted through a literature review, product observations, and interviews, it can be concluded that goalkeeper activities involve a relatively high risk of impact, particularly in body areas that frequently serve as points of contact when performing *diving* and landing movements. The shoulders, elbows, sides of the body or ribs, and hips are areas that require particular attention in the development of additional protective measures.

Padding materials have a significant influence on user comfort and flexibility. Materials with excessively dense or thick structures may provide better impact protection; however, they may also increase heat accumulation, add weight, and restrict body movement during high-intensity activities. Conversely, materials with more open structures can improve air circulation and thermal comfort, but their impact attenuation capability may be insufficient when applied as the primary protective component. Therefore, selecting padding materials requires a balance between impact absorption performance and ergonomic considerations.

However, this study has several limitations. The evaluation of padding materials was primarily based on literature reviews, product observations, and user interviews; therefore, the mechanical performance of the proposed material combinations, such as impact attenuation capacity, compression behavior, and thermal performance, was not experimentally measured. Further research involving laboratory-based impact testing, biomechanical analysis, and user performance evaluation is required to validate the effectiveness of the proposed padding system for goalkeeper undershirts.

The ability of a material to absorb impact is influenced by its type, structure, mechanical characteristics, and thickness. Based on the findings of the study, impact-absorbing materials such as *foam* can be used in areas with a high risk of impact, while *spacer fabric* can be considered as a supporting material to improve ventilation and comfort.

Thus, a suitable material concept for a goalkeeper *undershirt* is a system that combines protective capabilities, flexibility, light weight, and thermal comfort. The combination of impact-absorbing materials with open-structured materials can serve as a basis for developing a more ergonomic *padding* system that is appropriate for the activity requirements of goalkeepers.

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None

Author Contributions Statement

GS contributed to the conceptualization of the study, development of the ergonomic padding system, research design and implementation, data collection and analysis, and manuscript preparation. MN, contributed to the development of the research methodology, research supervision, validation of the results, interpretation of the findings, and review and editing of the manuscript. Both authors have read and approved the final version of the manuscript.

AI Usage Statement

In this study, the use of Artificial Intelligence (AI) tools was strictly limited to supportive functions, including language editing, grammar checking, and improving the clarity and readability of the manuscript. AI was not used to generate core research ideas, conduct substantive analysis, interpret data, or draw scholarly conclusions. The authors retain full responsibility for the originality, accuracy, and academic integrity of the content. AI tools were not credited as authors or contributors, in accordance with ethical standards in academic publishing.

Conflict of Interest

The authors declare that there is no conflict of interest, either financial or non-financial, that could have influenced the conduct of the research, data analysis, interpretation of the results, or preparation of this manuscript.

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